

AMENDMENTS TO THE SPECIFICATION

Please substitute the following replacement paragraph(s) [0001], [0038], [0049], [0100], [0101], [0102], [0119], [0120], [0121], [0125], [0126], [0129], [0131], [0132], [0137], [0140], [0146], [0148] and [0155] for the previously-pending versions of such paragraph(s). Each of these replacement paragraph(s) are amended herein, and marked-up to show changes from the previously-pending versions thereof.

[0001] This application is a continuation-in-part of co-owned, co-pending U.S. patent application Ser. No. 09/518,794, entitled “Chemical Processing Microsystems, Diffusion-Mixed Microreactors and Methods for Preparing and Using Same”, filed March 3, 2000 by Bergh *et al.*, now issued as U.S. Patent No. 6,749,814. The present invention is also related to, and claims priority to co-owned, co-pending U.S. patent application Ser. No. 60/187,566 entitled “Apparatus and Methods for Multi-Variable Optimization of Reaction Systems and Other Chemical Processing Microsystems”, filed March 7, 2000 by Bergh *et al.*, and to co-owned, co-pending U.S. patent application Ser. No. 60/229,984 entitled “Apparatus and Methods for Optimization of Process Variables in Reaction Systems and Other Chemical Processing Systems”, filed September 2, 2001 by Bergh *et al.*, each now abandoned in favor of the present application.

[0038] The present invention is related to the following patents and/or patent applications, each of which is hereby incorporated by reference for all purposes, including for the purpose of combination of various features disclosed in the various related applications to various features disclosed herein, to the highest extent practical, based on the knowledge in the art, and coupled with the guidance of this application and the related applications: (1) co-owned, co-pending U.S. patent application Ser. No. 60/187,566 entitled “Apparatus and Methods for Multi-Variable Optimization of Reaction Systems and Other Chemical Processing Microsystems”, filed March 7, 2000 by Bergh *et al.*, now abandoned in favor of the present application; (2) co-owned, co-pending U.S. patent application Ser. No. 60/229,984 entitled “Apparatus and Methods for Optimization of Process Variables in Reaction Systems and Other Chemical Processing Systems”, filed September 2, 2001 by Bergh *et al.*, now abandoned in favor of the present application; (3) co-owned, co-pending U.S. patent application Ser. No. 09/093,870, entitled

“Parallel Fixed-Bed Reactor and Fluid Contacting Apparatus and Method”, filed June 9, 1998 by Guan *et al.*, and now issued as U.S. Patent No. 6,149,882; (4) to co-owned, co-pending U.S. patent application Ser. No. 09/518,794, entitled “Chemical Processing Microsystems, Diffusion-Mixed Microreactors and Methods for Preparing and Using Same”, filed March 3, 2000 by Bergh *et al.*, issued as U.S. Patent No. 6,749,814; (5) U.S. Serial No. 60/274,065, entitled “Parallel Flow Reactor Having Improved Thermal Control” filed on ~~the date even herewith~~ (March 7, 2001) by Bergh *et al.*, abandoned in favor of U.S. Ser. No. 10/094,257 (pending and published as US 2002-0170976); (6) U.S. Serial No. 60/274,022, entitled “Gas Chromatograph Injection Valve Having Microvalve Array” filed on ~~the date even herewith~~ (March 7, 2001) by Bergh *et al.*, abandoned in favor of U.S. Ser. No. 10/092,364 (pending and published as US 2002-0127146) and in favor of U.S. Ser. No. 10/092,035 (issued as U.S. Patent No. 6,742,544); and (7) U.S. Serial No. 09/801,430 entitled “Parallel Gas Chromatograph With Microdetector Array” filed on ~~the date even herewith~~ (March 7, 2001) by Srinivasan *et al.* (issued as U.S. Patent No. 6,701,774). Further reference to several of these applications is made below, in the context of the present invention.

[0049] In general, the particular nature, type, design and/or configuration of the flow restrictor is not narrowly critical. The inlet flow restrictors, outlet flow restrictors and/or feed-composition flow restrictors are a portion of a fluid distribution path that provides a resistance to flow, and typically, provides a greater resistance to flow than the immediately upstream portion of the fluid distribution path of the chemical processing system. For chemical reaction systems, the flow restrictors can provide a resistance to flow between a reactant source and the reactors, or between the reactors and an effluent sink. For a feed distribution system (or subsystem) the flow restrictors can provide a resistance to flow between a feed component source and a mixing zone (*e.g.*, mixing cavity, combined channel, reaction cavity, *etc.*). Preferred flow restrictors include passive flow restrictors such as capillaries, microcapillaries, small channels, channels having orifices, and microfluidic channels (*e.g.*, including microfabricated channels), among others. In preferred embodiments of the invention, discussed in further detail below, the flow restrictors are microfluidic channels, typically formed using microfabrication techniques, and can be integral with a substrate or with one or more microchip bodies mounted – fixedly or detachably – on a substrate. A further description of preferred flow restrictors is provided below, as well as in each

of the aforementioned co-pending patent applications of Guan *et al.* (now U.S. Patent No. 6,149,882) and of Bergh *et al.* (U.S. Ser. No. 09/518,794, issued as U.S. Patent No. 6,749,814). Although flow control is preferably effected with flow restrictors, in some embodiments of the invention, it is contemplated that active flow-control elements can be used to control flow. The use of such active flow-control elements can be advantageously effected, for example, in reaction system embodiments in which the active flow-control elements are microfabricated or are integral with a substrate or with one or more microbodies mounted on the substrate.

[0100] In a further embodiment, a set of four or more inlet flow restrictors, four or more outlet flow restrictors, and/or four or more feed-component flow restrictors (depending on the subsystem of interest), or a portion thereof, can be provided to the reactor system as a modular unit comprising one or more flow restrictors. The modular unit preferably comprises an essential absence of reactor components (*e.g.*, components having one or more surfaces that define the reaction cavity), but can in some embodiments, include such reactor components (*e.g.* See, for example, the aforementioned related U.S. patent application to Bergh *et al.* (U.S. Ser. No. 09/518,794, issued as U.S. Patent No. 6,749,814). The modular unit can, in either case, also include other components of the fluid distribution system or subsystems, including for example valves (*e.g.*, selection valves, isolation valves) pressure sensors, flow sensors, interface connections, *etc.*).

[0101] In a preferred embodiment, the modular unit can be a modular fluidic chip comprising a substrate and one or more flow restrictors integral therewith (*e.g.*, formed at least partially at, on or in the substrate). The substrate having integral flow restrictors can be the modular fluidic chip substrate itself, or alternatively, can be one or more microchip bodies mounted, fixedly or detachably, onto the microfluidic chip substrate (*i.e.*, where the microfluidic chip is a primary substrate, with secondary substrates comprising the flow restrictors being mounted thereon). In general, both of such embodiments can be considered to be within the scope of the characterization of the flow restrictors as being integral with either a substrate or with one or more microchip bodies mounted on a substrate. The modular fluidic chip is preferably a plate-type substrate or block-type unit, and can comprise, for example, one or more substrates having one or more channels of controlled geometry operating as flow restrictors integral therewith or

with one or more microchip bodies mounted thereon. The substrate or one more microchip bodies can comprise a plurality of laminae in which one or more flow restrictors are formed. Methods for producing such modular fluidic chip devices are generally known in various arts (*e.g.*, circuit manufacturing), and are described below in connection with preferred embodiments of the invention. Such methods are also described in some detail in connection with related fluid distribution applications in the above-referenced co-pending application of Bergh *et al.* (U.S. Ser. No. 09/518,794, issued as U.S. Patent No. 6,749,814). The modular fluidic chip can include other components, in addition to the one or more flow restrictors, including for example, microvalves (*e.g.*, isolation valves), thermal conductivity detectors, flow-rate detectors, pressure sensors, and temperature sensors, among others. Such other components can be integral with a substrate or with one or more microchip bodies mounted on a substrate – either the same substrate / microchip bodies as the flow restrictors or different substrates / microchip bodies as the flow restrictors.

[0102] Modular fluidic chips can be employed as a single modular fluidic chip (including, for example, a plurality of flow restrictors for use as described above in connection with a plurality of reactors), or alternatively as a plurality of modular fluidic chips. Moreover, such modular fluid chips can be integrated with other, microscale reaction system components (*e.g.*, microreactors, microsensors, etc.), as described below and/or as described in, or varied from, the co-pending application of Bergh *et al.* (U.S. Ser. No. 09/518,794, issued as U.S. Patent No. 6,749,814) and/or the co-pending application of Guan *et al.* (now U.S. Patent No. 6,149,882). Such modular fluid chips can also be integrated with larger scale reaction system components.

[0119] Process temperature (*e.g.*, reaction temperature) can be controllably varied in combination with the aforementioned approaches for controlling reactor feed compositions, reactant flow rates and reactor pressure. With further reference to Figure 7A, for example, the chemical processing system 10 can also include a temperature control system (not shown) adapted to provide a temperature gradient or other desired temperature variation across the array 100 of reactors 600. The temperature control can be for a group of reactors or for individual reactors, as desired, and can generally be as described below, and also as described in the Guan

et al. (U.S. Patent No. 6,149,882) and Bergh *et al.* (U.S. Serial No. 09/518,794, issued as U.S. Patent No. 6,749,814) applications.

[0120] Particular approaches for varying temperatures across a library of candidate catalysts can vary depending on the particular type of reactor system employed. Exemplary approaches for varying temperature across a library of different candidate materials are disclosed in connection with the aforementioned co-pending applications of Guan *et al.* (U.S. Patent No. 6,149,882) and of Bergh *et al.* (U.S. Serial No. 09/518,794, issued as U.S. Patent No. 6,749,814). In one approach, a temperature gradient can be advantageously applied to one or more embodiments of reaction systems (or, other chemical processing systems) where the number of reactors seeing different temperatures is substantially enhanced, by orientating an array of reactors in a slightly skewed manner relative to the orientation of the temperature-contours (lines of constant temperature). The embodiment shown and discussed in connection with Figures 8E is exemplary.

[0121] Particularly preferred parallel flow reaction systems can include a reactor module that comprises four or more parallel flow reactors having separate and independent temperature control for each of the four or more reactors. Substantial thermal management challenges exist for such reactor modules in which the four or more flow reactors are close-packed – that is, in which the four or more reactors have a spatial density (taken along one or more cross-sections) of not less than about 1 reactor / 100 cm², preferably not less than about 1 reactor / 50 cm², more preferably not less than about 1 reactor / 10 cm², and, in some applications, not less than about 1 reactor / cm², not less than about 2 reactors / cm², not less than about 1 reactor / mm². A preferred approach for establishing thermal independence between each of the four or more reactors, such that simultaneous independent temperature control can be effected for each of the four or more reactors without substantial thermal interference from adjacent reactors is disclosed in U.S. Serial No. 60/274,065, entitled “Parallel Flow Reactor Having Improved Thermal Control” filed on ~~the date even herewith~~ (March 7, 2001) by Bergh *et al.*, abandoned in favor of U.S. Ser. No. 10/094,257 (pending and published as US 2002-0170976). Briefly, as described therein, independent temperature control for each of the four or more reactors is effected using separately-controlled heating elements (e.g. resistive heating elements such as coil heaters)

around each of the four or more reactors, while thermal isolation between the four or more reactors is accomplished by fluid-based heat exchange with an external heat sink. In preferred embodiments, the heat flux being applied to each of the reactors has an axial profile (taken along the length of the flow reactor, with the direction of flow) that can be varied (fixedly varied, or controllably varied) to compensate for variations in the heat-flux profile associated with the circulating heat-exchange fluid cooling the reactors, and to compensate for the varied locations of the four or more reactors relative to other reactors and to the external environment (*e.g.* centered reactors versus reactors near an external edge of the reactor module). Hence, design and/or control of the heating elements for each of the reactors can effect a substantially axially-uniform temperature profile for each of the four or more independently. Although especially useful in connection with parallel flow reactors, the temperature-control system disclosed in the aforementioned patent application can have applications for control of other types of reaction systems (*e.g.*, batch reactors, semi-continuous reactors) and/or in non-reaction chemical processing systems (*e.g.* calcining of heterogeneous catalysts) where parallel, independent temperature control is desirable.

[0125] Each of the chemical reaction systems and/or chemical processing system can further comprise a detection system 1000 (*e.g.*, parallel gas chromatograph). A number of detection schemes suitable for high-throughput, multi-channel reaction systems are known in the art and can be employed in connection with the present invention. Exemplary general detection approaches include, without limitation, parallel, quasi-parallel (hybrid parallel-serial) or rapid serial approaches involving, for example, gas chromatography (GC), mass spectrometry (MS), infrared spectroscopy (*e.g.*, fourier-transformed infrared (FTIR) spectroscopy), liquid chromatography (LC), thin-layer chromatography (TLC), selective adsorption of reaction products and/or unreacted reactants, *etc.* Parallel approaches such as parallel gas chromatography (GC), parallel-fast GC, parallel time-of-flight mass spectrometry (TOF-MS) are particularly preferred. Without limitation, preferred detection apparatus and methods are disclosed in the aforementioned U.S. patent applications of Guan *et al.* (U.S. Patent No. 6,149,882), Bergh *et al.* (U.S. Serial No. 09/518,794, issued as U.S. Patent No. 6,749,814), as well as in U.S. Patent No. 5,959,297 to Weinberg *et al.* entitled "Mass Spectrometers and Methods for Rapid Screening of Libraries of Different Materials". The detection system can

include distribution valves and/or selection valves (not shown in Figure 7C) as described in the Guan *et al.* and the Bergh *et al.* applications, for multiplexed selective sampling. An array of addressable microvalves, discussed below in connection with Figures 9A and 9B, can also be advantageously employed in connection with the detection system 1000.

[0126] A detection system especially preferred for use in connection with the reaction system of the present invention can comprise a multi-channel gas chromatograph as disclosed in co-owned, co-pending U.S. Serial. No. 60/222,540, entitled "Parallel Gas Chromatograph with Microdetector Array" filed August 2, 2000 by Srinivasan *et al.*, as well as in U.S. Serial No. 09/801,430, entitled "Parallel Gas Chromatograph with Microdetector Array" filed on ~~the date even herewith~~ (March 7, 2001) by Srinivasan *et al.* (issued as U.S. Patent No. 6,701,774). Reactor effluents discharged from each of the four or more reactors can be simultaneously injected into such a multi-channel (*i.e.* parallel) gas chromatograph using a parallel injection valve, such as is disclosed in U.S. Serial No. 60/274,022, entitled "Gas Chromatograph Injection Valve Having Microvalve Array" filed on ~~the date even herewith~~ (March 7, 2001) by Bergh *et al.*, abandoned in favor of U.S. Ser. No. 10/092,364 (pending and published as US 2002-0127146) and in favor of U.S. Ser. No. 10/092,035 (issued as U.S. Patent No. 6,742,544).

[0129] In each of the aforementioned chemical reaction systems, the four or more reactors can be of any suitable design, including for example designs modeling or substantially modeling continuous-stirred-tank reactors (CSTR's), fixed bed reactors, fluidized bed reactors, plug-flow reactors, channel-type reactors, *etc.*. Designs modeling or substantially modeling fixed bed, plug-flow and CSTR-type reactors are preferred. The aforementioned co-pending patent applications of Guan *et al.* (filed June 9, 1998) and of Bergh *et al.* (U.S. Serial No. 09/518,794, issued as U.S. Patent No. 6,749,814) include preferred reactor and reactor configuration designs. The reactor types in a particular chemical reaction system can be identical to each other, substantially the same as each other, or varied (*e.g.*, for optimization of reactor-type) in a particular chemical reaction system.

[0131] The plurality of reactors are two or more reactors, preferably four or more reactors, and more preferably nine or more reactors. Higher numbers of reactors, including sixteen, twenty-four, forty-eight or ninety-six or more reactors are contemplated. When an array of microreactors is used in connection with the invention, the number of reactors can be hundreds or thousands. Additional general features of the reactors together with preferred number of reactors, reactor types, types of candidate materials optionally included within the reactors (especially catalyst candidate materials), variations in composition of the candidate materials (especially variations in catalysts and/or catalyst precursors) loading / unloading of candidate materials into / from the reactors, configurations of arrays of reactors, planar densities of reactors, specific reactor designs, and reactor fabrication approaches are as described in the aforementioned co-pending U.S. patent applications of Guan *et al.* (U.S. Patent No. 6,149,882) and Bergh *et al.* (U.S. Serial No. 09/518,794, issued as U.S. Patent No. 6,749,814), collectively referred to hereinafter as the “Guan *et al.* and Bergh *et al.* applications.” Such additional general features are hereby specifically incorporated by reference.

[0132] Referring to Figure 8A, an integrated chemical reaction system 10 comprising a flow-through reactor design (*e.g.*, analogous to a plug-flow reactor) can comprise a plurality of microreactors 600 formed in one or more laminae 100. The material-containing laminate 100 comprises a candidate material 920 such as bulk catalyst (*e.g.*, as beads, pellets or particulates, *etc.*) or supported catalysts contained within the microreactors by a porous barrier 126 (*e.g.*, frits, porous plug, *etc.*, as described above). As shown, the plurality of microreactors 600 are sealed and heated by adjacent temperature control blocks – shown as adjacent heaters 980 – with releasable seals 300 (*e.g.*, gaskets, such as metal gaskets with optional knife-edge seal) situated between the heaters 980 and the microreactor laminae 100. Reactants 20 are provided to the microreactors 600 through an inlet distribution manifold 500 in fluid communication with the microreactors 600 via connecting channels 550. The distribution manifold can comprise a first set of inlet flow restrictors (not shown in Figure 8A), and optionally, a feed-composition varying subsystems (not shown in Figure 8A), as described above. The distribution manifold 500 is thermally isolated from the microreactors 600 by temperature control block 400. After contacting the candidate materials (*e.g.*, catalysts) 920 under reaction conditions, reactor effluent 60 is passed through connection channels 550 to a discharge manifold 501, and further to an

external distribution (waste) system. The discharge manifold 501 can comprise a second set of outlet flow restrictors (not shown in Figure 8A). The discharge manifold 501 is likewise thermally insulated from the microreactors 600 by another temperature control block 400. Evaluation of the candidate materials can be determined by analysis of reaction products, for example, by sampling of the reactor effluent stream using one or more sampling probes 910 (*e.g.*, sampling needles) that are in selective fluid communication with one or more of the microreactors 600, and in further fluid communication with a detection system (*e.g.*, gas chromatograph, mass spectrometer, FTIR, *etc.*). A septum or other suitable accessible barrier 911 may be employed in connection with the sampling system. Reference is made to the earlier filed applications of Guan *et al.* (U.S. Patent No. 6,149,882) and especially Bergh *et al.* (U.S. Serial No. 09/518,794, issued as U.S. Patent No. 6,749,814) in connection with the embodiment shown in Figure 8A. A similar reaction system 10 is shown in Figure 8D, except that the outlet stream includes a “U-turn” to direct the effluent stream 60 to a discharge manifold 501 located in the vicinity of the inlet distribution manifold 500. This design has some advantages with respect to flow control interfacing (localized area) and with respect to temperature control (single “cold zone”).

[0137] An array of valves, preferably an array of microvalves can be employed in connection with the chemical processing systems of the invention (*e.g.*, a chemical reaction system 10 such as that shown and discussed in connection with Figure 8A), as well as with other chemical processing systems, such as those disclosed and discussed in the earlier-filed Bergh *et al.* application (U.S. Serial No. 09/518,794, issued as U.S. Patent No. 6,749,814). With reference to Figure 9A, for example, a pneumatically active microvalve array 2500 can comprise a plurality, and preferably four or more microvalves (2510 – not shown schematically) in operational communication with four or more microvalve actuators 2515 arranged and/or formed at, on or in a common substrate. The microvalve actuators can actuate the microvalves. In some embodiments, the common substrate can comprise a plurality of laminae, and the four or more microvalves and four or more microvalve actuators 2515 can be formed in the plurality of laminae. Each of the four or more microvalve actuators 2515 can be in selective fluid communication between a first pneumatic valve actuating line 2530a, 2530b of a first set 2530 of actuating lines, and a second pneumatic valve actuating line sample line 2550a, 2550b of a

second set 2550 of actuating lines. Collectively, the four or more microvalve actuators are in selective fluid communication between the sets of first and second valve actuating lines 2530 and lines 2550. As shown, each of the four or more actuating flowpaths comprises an actuator inlet 2512 in fluid communication with at least one of the first actuating lines 2530a, 2530b, and an actuator outlet 2514 in fluid communication with at least one of the second actuating lines 2550a, 2550b, and in selective fluid communication with the actuator inlet 2512. A valve control logic 2514 can provide for selective, controlled actuation of the microvalve actuator 2515 for operation of valve 2510. One or more flow restrictors 2516 can be provided in the actuator flowpath (*i.e.*, between the actuator inlet 2512 and actuator outlet 2514), including for example as shown, between the microvalve actuator 2515 and the actuator outlet 2414. With reference to Figure 9B, the valve control logic 2514 can vary depending on the particular application, but can typically be an “AND” or an “OR” logic, such that valve control for four or more valves can be controlled using microprocessor based technology with appropriate software. Although shown only with four or more microvalve actuators in the array, the number of microvalve actuators and microvalves can be substantially larger, including numbers that are the same as the number of reactors as described, for example, in the Guan *et al.* (U.S. Patent No. 6,149,882) and/or the Bergh *et al.* (U.S. Serial No. 09/518,794, issued as U.S. Patent No. 6,749,814) applications. As applied to chemical processing systems having arrays of larger numbers of components (*e.g.*, reactors; microvalve actuators) – such as 100 or more components, the number of actuation circuits can be increased by $\log N$ (where N is the number of components) rather than being increased by N – which is the case with a hierarchy of individually-dedicated actuators. The array of microvalve actuators and microvalves can be fabricated by methods known in the art. *See, for example:* Rich *et al.*, “An 8-Bit Microflow Controller Using Pneumatically-Actuated Valves”, pp. 130-134, IEEE (1999); Wang *et al.*, “A Parylene Micro Check Valve”, pp. 177-182, IEEE (1999); Xdeblick *et al.*, “Thermopneumatically Actuated Microvalves and Integrated Electro-Fluidic Circuits”, 251-255, TRF, Solid State Sensor and Actuator Workshop, Hilton Head, South Carolina, June 13-16 (1994); and Grosjean *et al.*, “A Practical Thermopneumatic Valve”, 147-152, IEEE (1999). In operation, the array of microvalves and microvalve actuators can provide for selective sampling and multiplexing of a plurality and preferably four or more reactor effluent streams, and can be interfaced, for example, with detection instruments such as parallel GC and/or parallel MS, among others. Individual reactor effluent streams, or groups or

subgroups of reactor effluent streams can be selectively sampled. The array of microvalves 2500 can be integrated with flow distribution systems, such as those disclosed herein, as well as with those disclosed in the Guan *et al.* and the Bergh *et. al.*, and can be used with numerous other applications.

[0140] The reaction systems of the present invention are particularly useful in connection with high-throughput (*i.e.*, combinatorial) catalysis research programs. Preferred approaches are disclosed in U.S. Patent No. 6,149,882 to Guan *et al.*, and U.S. Ser. No. 09/518,794 filed March 3, 2000 by Bergh *et al.*, issued as U.S. Patent No. 6,749,814. As applied to combinatorial (*i.e.*, high-throughput) research for heterogeneous catalysts, such MVO reactors can be employed in a work-flow paradigm in which an identified “lead composition” is efficiently optimized and evaluated for potential commercial applications. As represented schematically in Figure 10A, for example, a lead composition can be evaluated in an MVO reactor with respect to optimization of synthesis protocols, processing / treatment (*e.g.*, reduction) conditions, and/or reaction conditions. Data reduction from one or more of such optimization efforts can then be integrated as feedback into further investigations with the MVO, preferably moderated with economic evaluations based, for example, on economic models. Preferred variables in connection with each of the synthesis optimization, processing optimization, reaction optimization, reactor optimization, and catalyst optimization are summarized in Figure 10B.

[0146] The flow restrictor block 4510 also includes the six pairs of commonly-actuated inlet isolation microvalves 487, 489, as well as the outlet isolation valves 4580. These valves are preferably fabricated using precision machining techniques known in the art. Alternatively, the valves can be microfabricated, and can be integral with the flow-restrictor block 4510 or with a microchip body mounted thereon. The valves can also be, as noted above, part of an external fluid distribution system (480, Fig. 11b). The particular microvalve design is not critical. Preferably, the microvalves 487, 489 are membrane-actuated, membrane-seated valves such as shown in Figures 11H and 11I. Briefly, membrane-actuated valves 4300 can be prepared by precision machining to form the various component parts. In its open state (Fig. 11H), a fluid can flow into the valve through fluid inlet passage 4302, through internal passages 4303, past the valve seat 4310, and out through outlet passage 4304. In its closed state (Fig. 11I), a piston 4320

having a piston face 4322 is forced upward against a seating membrane 4315 such that fluid flow past the seat 4310 is sealingly blocked, with the seating membrane 4315 essentially acting as a gasket between the piston face 4322 and the valve seat 4310. The piston 4320 is preferably pneumatically actuated by use of an actuating membrane 4325 under pressure through actuation passage 4330. Portions of the seating membrane 4315 and actuating membrane that are situated between facing component surfaces of the valve body can serve as gaskets when the valve is clamped or fastened together. Further details are provided in co-pending, co-owned application U.S. Serial No. 60/274,022, entitled "Gas Chromatograph Injection Valve Having Microvalve Array" filed on ~~the date even herewith~~ (March 7, 2001) by Bergh *et al.*, abandoned in favor of U.S. Ser. No. 10/092,364 (pending and published as US 2002-0127146) and in favor of U.S. Ser. No. 10/092,035 (issued as U.S. Patent No. 6,742,544).

[0148] The reactor module 4600, shown schematically in Figure 11O, comprises a 4x6 array of twenty-four reactor tubes 4610 individually supported in a reactor frame 4605. Each tube has a reaction volume of about 1 ml. Each of the reactor tubes 4610 can be individually heated using resistive coil heaters 4620 (*e.g.* Watlow Mini-K-ring). Thermal isolation between reactor tubes 4610 is achieved using fluid-type heat exchanger to cool the inter-reactor volume within the reactor frame 4610. Preferably, the cooling medium is air or inert gas, and is fed into the reactor module 4600 substantially at the midsection thereof. Plate cooling fluid (*e.g.* air) is also fed through the top member 4606 and bottom member 4607 of the reactor frame 4605, specifically through heat-exchange channels 4608 formed therein. Advantageously, as described in greater detail above, the heat flux associated with the resistive coil heaters 4620 can be axially varied to account for heat variations due to the reaction, and to balance heat removal by the cooling media such that a substantially axial uniform temperature profile is obtained. Further details about temperature control are provided in co-owned, co-pending application U.S. Serial No. 60/274,065, entitled "Parallel Flow Reactor Having Improved Thermal Control" filed on ~~the date even herewith~~ (March 7, 2001) by Bergh *et al.*, abandoned in favor of U.S. Ser. No. 10/094,257 (pending and published as US 2002-0170976). The feed gas flows into the reactor tube inlet 4612, and optionally contacts a catalyst (*e.g.*, supported in the reactor tube using frits (not shown)) under reaction conditions to effect the chemical reaction of interest. The reaction products and unreacted reactants are discharged through the reactor tube outlet 4614.

[0155] In a preferred embodiment for formulation and synthesis applications, a fluid distribution system can advantageously simultaneously form four or more fluid compositions comprising at least two or more components in varying relative amounts. The fluid distribution system can comprise four or more mixing zones for forming the four or more fluid compositions, and a first feed component source in fluid communication with each of the four or more mixing zones, via a set of four or more first-feed-component flow restrictors. Each of the four or more first-feed-component flow restrictors provide fluid communication between the first feed component source and one of the four or more mixing zones, and each have a flow resistance that varies relative to other first-feed-component flow restrictors in the set. A second feed component source is also in fluid communication with each of the four or more mixing zones. Hence, although described herein in connection with controlling feed composition to a flow reactor or other flow processing system, the concept of using flow-partitioning to form varying compositions in a mixing zone also has applications in other aspects of combinatorial material science research, such as in material synthesis applications (*e.g.*, catalyst synthesis or catalyst precursor synthesis). Such synthesis applications include those described in co-owned and co-pending U.S. patent application Ser. No. 09/516,669, entitled "Method and System for In-Situ Synthesis of a Combinatorial Library of Supported Catalyst Materials", filed March 1, 2000 by Lugmair *et al.*, issued as U.S. Patent No. 6,627,571.

[NO FUTHER AMENDMENTS THIS PAGE]